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ScienceDirect

Procedia Engineering 112 (2015) 556 – 561

Procedia Engineering

www.elsevier.com/locate/procedia

7th Asia-Pacific Congress on Sports Technology, APCST 2015

An Evaluation of the Riddell IQ HITS System in Prediction of an Athlete's Head Acceleration

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Abstract

This paper explores the accuracy of the Riddell IQ HITS system in predicting an athlete's head acceleration. The data will be useful in efforts made to determine methods of reducing the risk of concussion. A Hybrid III anthropomorphic head was instrumented with a triaxial accelerometer, fitted with a Riddell IQ HITS helmet, and dropped onto a hard steel plate at varying impact angles. The resulting accelerations were recorded and compared for each angle. High speed camera images were also examined to better analyze the rigid body motion of the helmet relative to the head. The results showed that the HITS system agreed with the measured Hybrid III accelerations at angles near the crown of the head, but did not agree well with most of the other angles, especially for oblique impacts near the side or back of the head. High speed images verified that this discrepancy was caused by the rigid body motion of the helmet relative to the head. The results also showed that the precision of the system depends strongly on the loading conditions of the impact. Further investigation is needed to determine the accuracy of the system for rotational acceleration.

Peer-review under responsibility of the the School of Aerospace, Mechanical and Manufacturing Engineering, RMIT University

Keywords: Hybrid III, helmet, head impact, oblique impact

1. Introduction

Concussions, or traumatic brain injuries (TBIs), are caused by a blow or other traumatic injury to the head. The injury can range from mild to severe, and until recently the causes and long-term effects had been understudied or unknown. It is now known that a serious TBI can disrupt the centers of the brain responsible for breathing, cognitive disturbances, and poor balance. It is also known that the risk for these symptoms greatly increases with repeated

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Peer-review under responsibility of the the School of Aerospace, Mechanical and Manufacturing Engineering, RMIT University
doi:10.1016/j.proeng.2015.07.244

injury. Over 3.8 million sports-related TBIs occur annually in the United States (U.S.), although the amount and severity varies by sport [1]. While no helmet can prevent a TBI, risks could be reduced with proper understanding about the mechanisms that cause these injuries.

The leading theory for the cause of a TBI is that linear and rotational accelerations due to both direct (impact) and inertial (whiplash) loading of the head deforms brain tissue, inducing stress. Although this strain is believed to be the primary cause of the injury, the exact mechanism by which this occurs is still uncertain [1]. Attempts at finding exact injury thresholds based on accelerations have been ongoing for over 50 years, although many today agree on a threshold around 90 g linear acceleration [2] [3] [4].

An easy way to ascertain how these accelerations act on athletes in the real world would be to outfit them with accelerometers, but since an accelerometer cannot simply be placed at the center of gravity (COG) of an athlete's head, alternative methods must be used. One well-known system used in football with a large amount of field test data is the Riddell Revolution IQ Hits football helmet. This helmet is equipped with built-in accelerometers that measure the acceleration of the helmet and estimate the acceleration of the head under the helmet. This paper examines the accuracy of this system.

2. Methods

The rigid body motion of a helmet is different from that of the athlete's head. In order to investigate this difference, an instrumented helmet and a triaxial accelerometer inside a Hybrid III head were dropped vertically onto a solid plate using a drop tower. The data gathered from this test were compared and correction factors were calculated to attempt to quantify the effects of the motion of the helmet.

2.1. Apparatus

The drop tower used in this test consisted of a sled that was raised and dropped, running along vertical rails. The Hybrid III head and neck were mounted to the sled via an attachment that allowed the angle of the head, relative to the vertical, to be changed. The head was rotated on the mount to allow for sagittal and lateral testing. An image of this tower and the two orientations of the head are shown in Fig. 1.

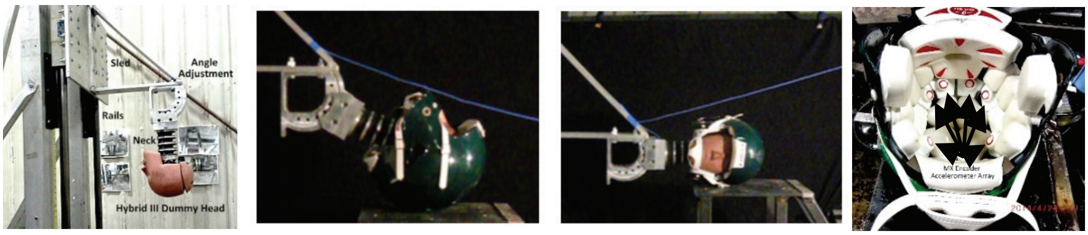

Fig. 1. (a) sled and head/neck assembly; (b) sagittal orientation; (c) lateral orientation; (d) Riddell football helmet with MX Encoder accelerometer array

The helmet used in testing was a Riddell Revolution IQ helmet, size XL, with the facemask removed, and equipped with Riddell's MX Encoder accelerometer array. The MX Encoder was placed in the helmet as shown in Fig. 1(d). A consistent fitting procedure was followed for each test:

1. Check Hybrid III head to ensure all fasteners are tightened properly.
2. Check football helmet pads, guards, and sensors.
3. Deflate inflatable pads, insert Hybrid III head into helmet, and carefully connect chin straps to predefined settings.
4. Inflate top inflatable pad to 5.80 PSI (40kPa).
5. Check level of head, lateral leveling across front of helmet, and anterior-posterior leveling of helmet.
6. Inflate cheek pads to 0.435 PSI (3kPa), and inflate rear pads to 1.52 PSI (10.5kPa).

7. Wait for 5 minutes and repeat 4-6 two times.

2.2. Data acquisition

The Riddell IQ HITS system gathered data using the MX Encoder, which is an array of 6 single axis accelerometers and wireless sensors that recorded impacts and wirelessly broadcasted them to a Wireless Receiver connected to a laptop running Riddell's IQ HITS software. This software was then synced with Riddell's Redzone website (*redzone.riddell.com*) where the data was processed with Riddell's custom algorithm and the results were viewed.

The accelerometer used in the Hybrid III head was a model 356A25 triaxial accelerometer from PCB Piezotronics which had a range of ±200 g peak, a sensitivity of 25 mV/g, and operating frequencies between 1-5k Hz. It was mounted inside the Hybrid III head cavity at the COG using the adhesive wax supplied with the accelerometer from PCB. A model 482C Series 4-channel sensor signal conditioner from PCB was connected between the accelerometer and a National Instruments BNC-2120 terminal block. A National Instruments PCI-6014 data acquisition card was installed in a desktop computer to record the data.

The camera used to record each experimental run was a CASIO High Speed Exilim EX-FH100 set to a capture rate of 420 frames per second and a resolution of 224 x 168.

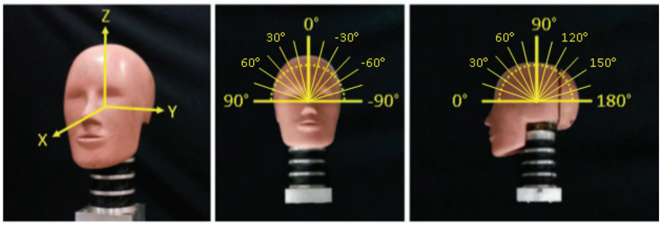

Fig. 2. (a) head coordinate system; (b) lateral plane angles; (c) sagittal plane angles

2.3. Coordinate system

A universal coordinate system fixed to the head was used to designate the orientation of the head and the locations of impact for each test. The triaxial accelerometer was mounted in the head with the positive x direction out of the face, the positive z out the top of the head, and the positive y out the left side of the head. Impact angles were recorded based on the plane in which they occurred. The lateral plane divided the head along the y-z plane with 0° being the crown of the head and increasing positively to the right and negatively to the left. The sagittal plane divided the head in half along the x-z plane with 0° being the positive x axis. Schematics of the coordinate system can be seen in Fig. 2.

2.4. Procedure

Each test began by mounting the helmet on the Hybrid III head. The impact angle was then set and the sled was raised and released using the quick-release mechanism. After each run the helmet was removed and replaced using the procedure above for consistency. Data was gathered for three runs at impact angles of 45° to 180° in the sagittal plane and 0° to 90° in the lateral plane, at 15° increments. All runs were dropped from a height where the impact surface of the helmet was 12 inches (30.5 cm) above the steel plate, which correlated to an impact speed of about 5.5 mph (2.46 m/s). Seventeen impact angles were tested with three samples at each angle. Each sample was performed on two accelerometers for a total of 102 data samples.

3. Results and discussion

Data from each test was analyzed and the average linear accelerations were calculated for each accelerometer at each impact angle with a 95% confidence interval. The results were then compared. (For the purpose of simplicity, all deceleration values are expressed as positive accelerations in the figures.)

3.1. Sagittal plane

Fig. 3 compares the average peak linear accelerations and their corresponding uncertainties for both accelerometers at various impact angles in the sagittal plane with the uncertainty of each set of data determined using a 95% confidence interval.

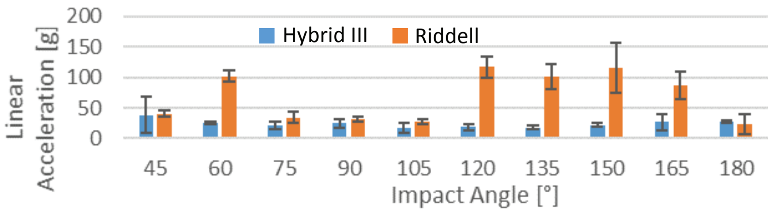

Fig. 3. Average peak linear accelerations and uncertainties for both accelerometers at varying sagittal impact angles

As shown in Fig. 3, average Hybrid III acceleration values were all very consistent with each other (with the exception of 45°), ranging from 26.77 g at 165° to 17.27 g at 105°. This was as expected since the helmet's padding was uniformly distributed along the sagittal plane, which should have resulted in even acceleration around the head. The high variability of the 45° impact was most likely due to the impact occurring at the very edge of the helmet.

The average acceleration values measured by the MX Encoder and the Riddell system did not follow a regular trend and agreed well at some angles (45°, 75°, 90°, 105°, and 180°), but were significantly higher at the rest of the angles. This is attributed to the motion of the helmet on the head. Even with the chin strap firmly in place, the rigid body motion of the head was different than that of the helmet, causing accelerometers in the helmet to read higher values compared to what the head was actually exposed to. Even small helmet shifting caused large effects in the results due to the sensitivity of the system. An example of the helmet shifting is shown for a 120° impact angle in Fig. 4.

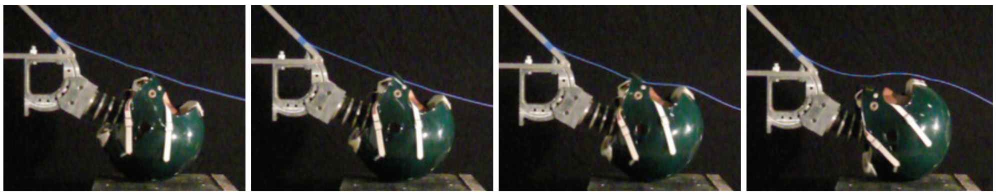

Fig. 4. Frames from high speed video showing helmet shifting on head at 120° sagittal impact

3.2. Lateral plane

Fig. 5 compares the average peak linear accelerations and their corresponding uncertainties for both accelerometers at various impact angles in the lateral plane with the uncertainty of each set of data determined using a 95% confidence interval.

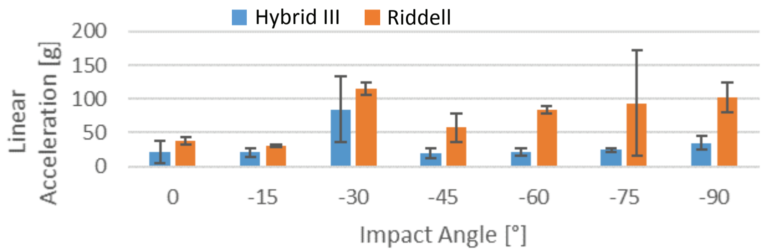

Fig. 5. Average linear acceleration and uncertainties for both accelerometers at varying lateral impact angles

The average Hybrid III acceleration values were again consistent around 20 g, with the exception of the value at -30°, which was over 80 g. This phenomenon is most likely due to the Hybrid III head coming in contact with the MX Encoder (See Fig. 1(d) for MX Encoder placement inside the helmet) instead of the surrounding padding. While at the rest of the angles much of the impact energy was absorbed by the padding, at -30° the stiffer MX Encoder absorbed less energy resulting in a higher acceleration.

The values from the Riddell accelerometers were again inconsistent due to the same helmet shifting issue discussed above. A view of this occurring at a -90° lateral impact angle can be found in Fig. 6.

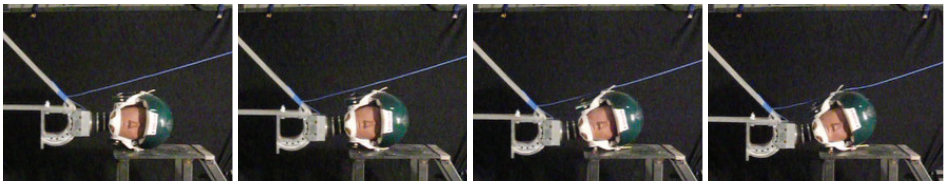

Fig. 6. Frames from high speed camera showing helmet shifting at -90° sagittal impact

3.3. Comparison

The results above show that the rigid body motion of the helmet was different from that of the head. To quantify this difference, a correction factor was developed. Fig. 7(a) compares the difference between the Riddell helmet readings and the Hybrid III accelerometer readings expressed as correction factors (a ratio of Riddell reading divided by the Hybrid III reading) for varying sagittal impact angles, and Fig. 7(b) shows the same for the lateral plane.

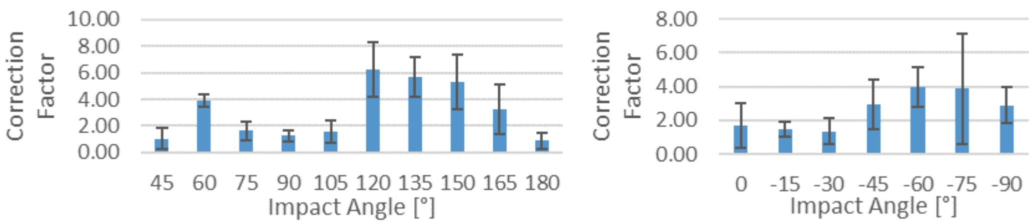

Fig. 7. (a) Correction factors [Riddell/Hybrid III] at varying sagittal plane impact angles; (b) Correction factors [Riddell/Hybrid III] at varying lateral plane impact angles

As discussed above, the helmet shifting around the head during impact caused very large inaccuracies in the HITS data. Consequently, the correction factors at those angles were very large and inconsistent from angle to angle. This shows that the HITS system is inaccurate for oblique impacts, especially at the back and sides of the head where the helmet is more prone to shifting on the head even with the chin strap properly in place.

3.4. Limitations

Several limitations exist in this study. First, having the facemask removed from the helmet may have led to increased deformation of the helmet. Further investigation would be needed, therefore, to assess this claim. Secondly, since the tests were conducted from only one height, the magnitude of the impacts remained relatively the same. More testing from varying heights would provide a better understanding of how much the magnitude of the impact affects accuracy. Finally, the Hybrid III head and neck system was used with the understanding of its own clear limitations in this type of testing. Other successful research has been conducted using this system [5], so the presented results can be trusted as much as the reader trusts the Hybrid III system. More investigation is also needed into how much chin strap tension, helmet inflation, etc., affect the shifting of the helmet during impact and, therefore, the accuracy of the HITS system.

4. Conclusions

This paper sought to investigate the accuracy of the HITS system in predicting the head acceleration of an athlete. A test was conducted comparing the average acceleration of a Hybrid III head and the predicted acceleration from the HITS system based on impacts on a solid plate at varying impact angles. Correction factors were developed to quantify the difference between these accelerations and high speed camera images were analyzed to help verify the results. The HITS system agreed with the measured acceleration at several impact angles, but the predicted accelerations were significantly higher than those measured at many angles, usually at locations that caused greater motion of the helmet relative to the head. These results show that slight changes in the loading of the impact on the helmet can cause great inaccuracies in the predicted head acceleration due to the high sensitivity of the system.

Acknowledgements

The authors would like to thank Hanna Rohl, Eric Rieder, and Chris Schwarz for their contributions to the research presented here. Funding was provided by the Mechanical Engineering Department, North Dakota State University.

References

[1] K. M. Guskiewicz and J. P. Mihalik, "Biomechanics of sport concussion: Quest for the elusive injury threshold," *Exercise Sport Science,* vol. 39, no. 1, pp. 4-11, 2011.
[2] L. Zhang, K. H. Yang and A. I. King, "A proposed injury threshold for mild traumatic brain injury," *Journal of Biomedical Engineering,* vol. 126, pp. 226-236, 2004.
[3] A. Post and B. T. Hoshizaki, "Mechanisms of brain impact injuries and their prediction: A review," *Trauma,* vol. 14, no. 4, pp. 327-349, 2012.
[4] C. F. Babbs, "A new biomechanical head injury criterion," *Journal of Mechanics in Medicine and Biology,* vol. 6, no. 4, pp. 349-371, 2006.
[5] E. J. Pellman, D. C. Viano, A. M. Tucker, I. R. Casson and J. F. Waeckerle, "Concussion in Professional Football: Reconstruction of Game Impacts and Injuries," *Neurosurgery,* vol. 53, pp. 799-814, 2003.